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AN ORGANIC COMPOSITE PHASE CHANGE MATERIAL FOR HOT FOOD STORAGE: A REVIEW

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ABSTRACT

The paper reviews about the implementation of Latent Heat Storage System in the food storage techniques, due to its high- energy density and isothermal nature. It helps in sustaining the temperature of the hot food for a long time, thus preventing the pathogen growth. Adverse effects are faced by the children due to the pathogen growth in the food. Reasons for the cause of foodborne illness in the children were discussed. The characteristics of the phase change material (PCM) for the latent heat storage was described in detail. Finally, preparation and commercial feasibility of the PCM were studied and presented.

KEYWORDS: Hot food Storage, Form Stable, FSM65, Microwavable PCM, Phase Change Material & Latent Heat Storage

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A Review

INTRODUCTION

Insulated food storage containers are used in recent times for food storage. In 1892, Sir James Dewar invented the “vacuum flask”. This invention took the food storage to the next level. It uses vacuum insulation between a double-walled stainless steel layers [1]. Insulated food containers are widely used to pack food especially for children. Usage of insulated food containers are recommended by various government and health organizations. Health Link BC (2011) recommends “parents should pack hot food in a thermos”. Childcare facilities encourage parents to use insulated containers for food storage because they don’t provide lunch or they don’t have enough facility or time to microwave the food. The lunch has to be stored for 5-6 hours from the time of packing in the morning, and that tooat a proper food holding temperature. Improper food holding temperatures may cause foodborne illness in children and some serious cases may even lead to death [1]. Food storage plays an important role, especially in the case of children. There are many techniques prevailing for food storage and this study provides an additional way of efficient food storage.

SIGNIFICANCE OF EATING HOT FOOD

Scientific studies say that there are many advantages of eating hot food. Less digestive effort, easy absorption of vitamins and minerals by the human body, long time preservation, and absence of insects over food are the advantages of eating hot food. 4°C - 60°C acts as the “DANGER ZONE”. In this temperature range, ideal condition prevails for the bacterial growth so that, its growth rate will be rapid and multiply at very high rate [1]. It has high possibility of causing food borne diseases among children (British Columbia FOODSAFE Secretariat, 2006). As the temperature of the hot food decreases, it offers more favorability for the growth and survival of

pathogens.

EFFECTS OF PATHOGEN GROWTH IN FOOD

Even though food borne illness won't be a great threat to adults, it is very dangerous to children. Adults have fully developed immune system, whereas children of 1-5 years don't have a fully developed immune system and thus have a high possibility of getting affected to foodborne illness [1]. Preparation in advance, improper storage and inadequate reheating are the common ways by which foodborne illness are caused (British Columbia FOODSAFE Secretariat, 2006). The top ten pathogens that cause foodborne illness in children are Campylobacter jejuni,Clostridium botulinum, Cyclopora, Escherichia coli O157:H7, Heptatis A, Listeria monocytogenes, Norovirus, Salmonella, Shigella and Vibiro (Canadian Food Inspection Agency, CFIA, 2011). The top ranked three pathogens which contribute to foodborne illness and deaths from 2000-2008 are Norovirus, Salmonella, Campylobacter. Salmonella and verotoxigenic E. coli infects infants and young children at a higher rate (Canadian Integrated Surveillance Report). Common childhood diseases and symptoms like diarrhoea, vomiting and nausea are caused by Norovirus and Campylobacter (BC Centre for Disease Control [BCCDC], 2009). Kidney failure and blood disorder may develop hemolytic uremic syndrome between 6 months and 4 years children due to serious E.coli infection (Public Health Agency of Canada, 2009).

PREVAILING TECHNIQUES FOR HOT FOOD STORAGE

Most common method prevailing for hot food storage is using insulated containers. And there are also other temporary techniques like foam containers, wrapping of aluminum foil, insulated lunch bags etc. But these temporary techniques are not widely used. Lunch for children are mostly packed in insulated containers. The "thermos" technology used vacuum insulation by evacuating the air from the gap between double-walled stainless steel. By eliminating conduction and convection it provides a better type of insulation. According to TherMax technology, a declaration was provided that it could keep food warm up to 5 hours (Thermos®, 2011b). Meat, cheese, rice, potato and dairy products are termed as potentially hazardous food stuffs, due to the high growth rate of pathogens (Frumkin, Geller, Rubin & Nodvin, 2006). Not enough study was made in the heat retention ability of insulated containers [1]. A research made by Cornell University says that there is better insulating efficiency and low pathogen growth rate in Foogo™ by Thermos®.

In 2011, Jackson Kwok, conducted an experimental research project on heat retention ability of insulated thermal containers. For analysis purpose he chose three thermal containers and concluded that none of them could sustain the temperature of above 60°C for more than 4 hours.

In 2013, Tiffany, H.T., Chu from British Columbia Institute of Technology used three different thermal insulated containers with Kraft Dinner Original macaroni and cheese [1]. The study says that the preheated containers comparatively hold food with less heat loss. He finally concluded that none of the containers, whether preheated or not could hold food above 60°C for more than 3 hours. And in recent times, latent heat storage system is implemented in hot food storage techniques.

PHASE CHANGE MATERIAL (PCM)

Phase change material act as thermal energy storage system. It is capable of storing large amount of heat. It involves sensible heat storage, latent heat storage and thermo-chemical storage. Sensible heat storage is characterized by raise in temperature. Latent heat storage is characterized by change in phase with a very small temperature change [2].

When the PCM is in solid form, its individual atoms are arranged in their respective lattice, by intermolecular force of attraction. It oscillates at a frequency about its average position in its lattice. As the temperature increases, internal energy of the atoms increase and the motion of the atoms become increasingly violent. Addition of heat, at the melting point, makes the intermolecular attractive forces no longer sufficient to maintain the stability of the lattice structure, the arrangement of the atoms in their respective lattice gets collapsed, and it becomes more disordered. Due to the collapse of the lattice arrangement of the atoms, the phase gets transformed to the liquid state and the atoms become free to move. During this process, the input heat (latent heat) won't be taking part in producing violent oscillations (i.e. the temperature of the substance almost remains constant), but it just increases the disorder of the atoms arrangement (i.e. the phase change occurs during latent heat transfer). Atul Sharma compared the heat storing capacity of the PCM, rock, and water [3]. Latent heat storage systems stores 5-14 times more than sensible heat storage systems [4].

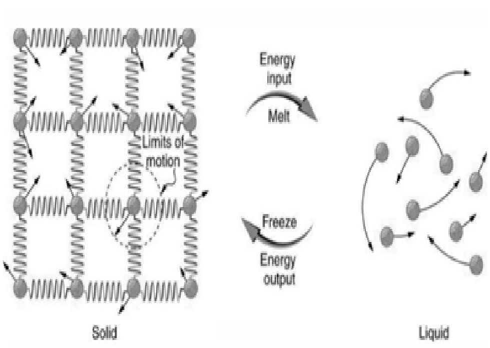


Figure 1: Latent Heat Transfer

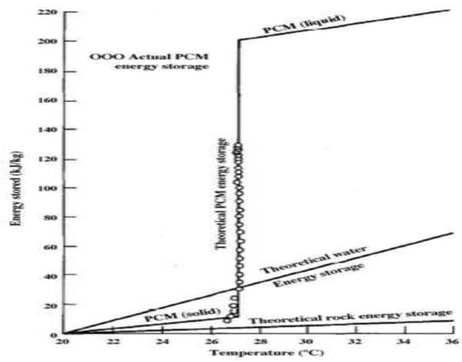


Figure 2. Comparison of Heat Storing Capacity of the Rock, Water and PCM [3]

The specific heat storage of the PCM is much greater than that of water, brick or stone [5]. Researchers are focusing on making of PCM composites with tailored melting point and improved properties, to suit a particular application [6-12]. PCMs are used as low temperature storage systems [14]. Researches are trying to implement PCM in high temperature zones [2]. When compared to sensible heat storage, latent heat storage involves much higher energy density with a minimum temperature swing [16]. Low thermal conductivity, density change, stability of properties under extended cycling, phase segregation, super-cooling are the common practical problems that arise in the method of latent heat storage [15]. PCMs are widely classified into organic, inorganic and eutectic [16]. Vasishta reviewed more than sixty phase change materials based on their thermal energy storage capacity [17]. George published a handbook for phase change thermal energy storage [13]. PCM with all the required properties for an application can't be actually available, because every phase change material has its own characteristic properties. Therefore the selection of PCM for a particular application depends upon the properties of PCM which suits the best for that particular situation [2].

According to the fundamental laws of thermodynamics, heat flows from a hot body to a cold body without any external work being done. The nature tries to nullify the temperature difference between the bodies. PCM is capable of producing both 'cooling effect' & 'warming effect'. For instance, let's consider that the PCM is placed in an ambient environment. Let T_{PCM} be the temperature of the PCM, T_{TRANS} be the phase change temperature of the PCM, T_S be the temperature of surroundings. During the heat transfer from the PCM, first sensible heat, then latent heat and finally again sensible heat is transferred [18]. Cooling effect is provided when $T_{PCM} < T_{S.}$ Warming effect is provided when $T_{PCM} > T_{S.}$ In case of cooling effect if both T_{PCM} and T_S are above or below $T_{TRANS,}$ then absorption of sensible heat only takes place

(cooling effect table, Case 1, 3). If $T_{PCM} < T_{TRANS} < T_{S,}$ then initially PCM will be in solid form and the T_{PCM} increases by absorbing sensible heat until it becomes equal to $T_{TRANS.}$ Once the state at which $T_{PCM} = T_{TRANS}$ is obtained absorption of latent heat takes place with the initiation of phase change process and it prevails until $T_{PCM} > T_{TRANS.}$ And then absorption of sensible heat takes place and at this stage the phase of the PCM would have been changed to liquid form (cooling effect table, Case 2). In case of warming effect if both T_{PCM} and T_S are above or below $T_{TRANS,}$ then rejection of sensible heat only takes place (warming effect table, Case 1, 3). If $T_S < T_{TRANS} < T_{PCM}$, then initially PCM will be in liquid form and the T_{PCM} decreases by rejecting sensible heat until it becomes equal to $T_{TRANS.}$ Once the state at which $T_{PCM} = T_{TRANS}$ is obtained rejection of latent heat takes place with the initiation of phase change process and it prevails until $T_{PCM} < T_{TRANS.}$ And then the rejection of sensible heat takes place and at this stage the phase of the PCM would have been changed to solid form (warming effect table, Case 2). And there will be no heat transfer if $T_{PCM} = T_{S.}$

Table 1: Warming Effect Table

Case	**WARMING EFFECT($T_{PCM} > T_S$)**	
1	$T_S < T_{PCM} < T_{TRANS}$	rejects sensible heat
2	$T_S < T_{TRANS} < T_{PCM}$	
• STAGE 1 $T_{PCM} > T_{TRANS}$		rejects sensible heat
• STAGE 2 $T_{PCM} = T_{TRANS}$		rejects latent heat
• STAGE 3 $T_{PCM} < T_{TRANS}$		rejects sensible heat
3	$T_{TRANS} < T_S < T_{PCM}$	rejects sensible heat

Table 2: Cooling Effect Table

Case	**COOLING EFFECT($T_{PCM} < T_S$)**	
1	$T_{PCM} < T_S < T_{TRANS}$	absorbs sensible heat
2	$T_{PCM} < T_{TRANS} < T_S$	
• STAGE 1 $T_{PCM} < T_{TRANS}$		absorbs sensible heat
• STAGE 2 $T_{PCM} = T_{TRANS}$		absorbs latent heat
• STAGE 3 $T_{PCM} > T_{TRANS}$		absorbs sensible heat
3	$T_{TRANS} <_{PCM} < T_S$	absorbs sensible heat

Heating the PCM results in ‘cooling effect’. Because the heat is absorbed by the PCM, and thus it tries to make the surrounding cool. Cooling the PCM results in ‘warming effect’. Because the heat is removed from the PCM and thus it makes the surrounding warm. During the reverse cooling of the charged PCM, for the condensation is about to start, temperature of the PCM has to go down below the transition temperature, to overcome the energy barrier for nucleation. This is known as sub-cooling [19].

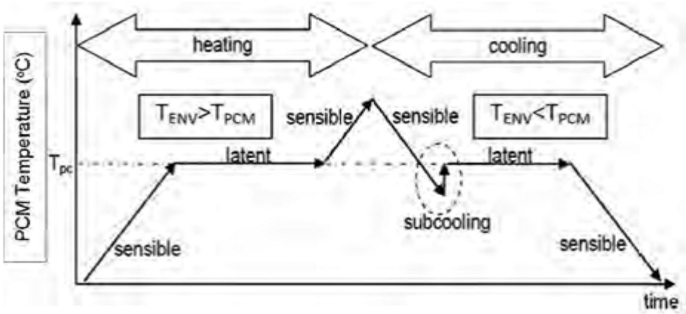
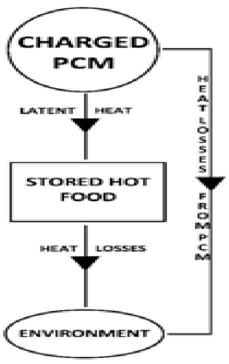


Figure 3: Phase Change Diagram of PCM [19]

IMPLEMENTATION OF PCM IN HOT FOOD STORAGE TECHNIQUES

The ultimate aim in the food storage technique is to keep the food hot at a safe hot holding temperature. One of the way to keep food hot is to prevent the heat losses from the food. Heat loss depends upon the efficiency of the insulation and emissivity of the food stuff. Whatever the effort we take in providing an efficient insulation, there will be heat loss from the food. Other way of solving this problem is by providing an equal amount of heat that is being lost. To make this possible an equal amount of heat should be pre-stored. So that, it could be provided to compensate the losses when it occurs. PCM can be used here as the heat storage system and its "warming effect" can be used to reject the heat when required. Usually conduction and radiation are the modes of heat transfer that take place between PCM and the food. A layer of PCM is packed in a pouch which is covered by a casing. The process of packing the PCM in the pouch is called as Macro-encapsulation, which increases the heat transfer area and helps in controlling the volume changes of the PCM [20, 21]. In most cases encapsulating materials are stainless steel, polypropylene and polyolefin [7]. Migration of the liquid state PCM is prevented due to encapsulation, so it does not form inflexible solid mass as it cools [16]. The casing setup is implemented as an inner temporary layer of the insulated food storage container in which the food is stored and it could be removed if necessary. The casing must be BPA-Free and non-toxic [22]. It shouldn't destroy the quality of food. A skillful engineer with the heat transfer and PCM knowledge can also implement it in other ways. But the ultimate aim is to establish an efficient way of heat transfer between the food and PCM, so that the temperature of food can be sustained for a long period.



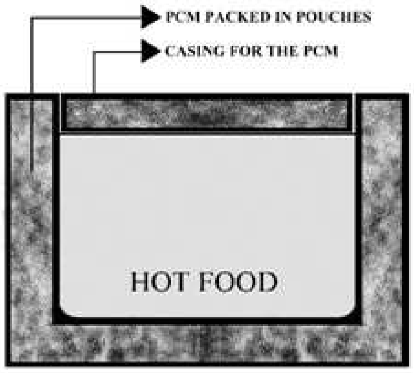


Figure 4: Flow Chart of the Heat Transfer Process

Figure 5: Cross-Sectional View of the PCM within the Casing

The pouch decreases the possibility of leakage. The casing acts as a container and it also serves the process of separation of food from the PCM. This is not the only way by which implementation of PCM in hot food storage technique

is achieved. Initially $T_{PCM}<T_{TRANS}<T_S$ prevails and PCM will be in solid state. The process of storing heat in the PCM (charging) is done by heating the casing using a heat source. Therefore the casing should be made of such a material that could withstand, with all kinds of heating like microwaving or using induction stove. The primary goal in preheating the casing is to charge the PCM, but the secondary advantage is, it becomes germfree. The procedure of preheating containers with boiling water is even recommended by Canadian Food Inspection Agency (2011b).

During charging of PCM the T_{PCM} rises due to the absorption of sensible heat until it reaches the state at which $T_{PCM}=T_{TRANS,}$ then absorption of latent heat and initiation of phase change from solid to liquid occurs until $T_{PCM} > T_{TRANS.}$ And then absorption of sensible heat takes place and at this stage PCM will be in liquid state. But only the transfer of latent heat will be dominant due to its high energy density [23]. The casing with charged PCM is placed in the insulated container and the hot food is stored. Let T_{FOOD} represents the temperature of food. The T_{FOOD} decreases due to the heat loss and when $T_{FOOD} < T_{PCM}$ heat transfer takes place from the PCM to the food. If $T_{PCM} > T_{TRANS}$ rejection of sensible heat takes place. If $T_{PCM}=T_{TRANS}$ rejection of latent heat takes and the large amount of heat is transferred only in the form of latent heat. If $T_{PCM} < T_{TRANS}$ again rejection of sensible heat takes place. Thus compensation of heat losses from the food is done by the implementation of the PCM.

REQUIRED CHARACTERISTICS OF PCM

In the application of food storage, the selection of PCM is mainly based on the transition temperature and the latent heat of fusion. The latent heat of fusion, transition temperature and specific heat of some of the PCMs were measured by Sharma [24]. The phase change temperature should lie between 65°C and 70°C. Both the transition temperature and latent heat of fusion increases as the chain length increase [25]. During the phase change process the PCM melts by absorbing latent heat. Sometimes melting of PCM results in the interaction of food, due to the damaged PCM pouches. To overcome this issue, a PCM composite has to be made whose physical form should be more stabilized, such that, it will not tend to flow even after phase change. The heating rate and mixture composition influence the transition temperature of the PCM composite [26]. Such a PCM composite is called as Form Stable PCM and its high viscosity don’t allow it to flow even in liquid states [27]. The process of preparing the From Stable PCM was proposed by Samit [27]. Shape-stabilized PCM (Form Stable PCM) can be prepared from PVC/Fatty acid blends [28]. The leakage of the PCM is prevented by the structural strength of the solid polymer [29]. The leakage of mass from the Form Stable PCM is decreased with the decreasing molecular weight of the PCM [30]. Form Stable PCM has good thermal reliability and chemical stability [31].

During the charging process of the PCM, hot spots are obtained due to its low thermal conductivity [32]. Many researchers made a theoretical study on the thermal performance of the PCM [33-38], and they proposed different methods to enhance its heat transfer efficiency [39]. The finned tubes of different configurations are used to enhance the heat transfer of the latent heat storage system [40-50]. Other techniques implemented for the improvement of heat transfer are insertion of PCM in metal matrix [51,52], dispersion of PCM with high conductive particles [53], micro encapsulation of PCM [54,55], usage of carbon fiber brushes with high thermal conductivity [56], embedded graphite matrix [57,58], enhancing thermal conductivity using exfoliated graphite [59], insertion of copper plates in spherical capsules [60], metal spheres inside the PCM [61], usage of aluminum foam [62], carbon loading to improve thermal conductivity [63]. The raise in temperature causes a slight increase in the thermal conductivity of the PCM. When the PCM is in liquid state, then the thermal conductivity of the PCM composite will be high. The slight increase in volume of the liquid state PCM,

increases the thermal conductivity of the PCM composite [64].

Zhang, [65, 66] conducted an experiment and found a way for the enhancement of heat transfer of PCM. Technical grade paraffin was taken and melted by heating it to 85°C. Paraffin wax comes under organic type of PCM. In a furnace raw expandable graphite was heated for 15 minutes at 700°C. By impregnating liquid paraffin in expanded graphite, paraffin composite with 7% mass fraction of expanded graphite is formed. This compound was experimentally found to have good thermal conductivity and it also occupies comparably less time for heat storage and retrieval [67]. Cabeza concluded that the PCM-graphite composite results in better heat transfer efficiency when compared with other techniques like addition of stainless steel and copper pieces [68]. PCM-graphite composite requires only half of the charging time of the pure PCM [69]. The thermal conductivity in the PCM-graphite composite will be several times higher than in the pure PCM [70].

The PCM should be capable of absorbing microwave energy, so that it could be also charged using domestic microwave oven. But also the casing and the pouch should be capable of withstanding microwave heating. The process of preparing the microwavable PCM was proposed by Samit [71,72]. The composition of the microwavable PCM comprises of microwave susceptor, binding agent and the phase change material. The susceptor and the PCM should be non-reactive. The microwave susceptor may be carbon black, graphite, ceramics, aluminum flakes or other microwave sensitive materials. The binding material such as clay provides suspension of susceptor particles and it also acts as slow microwave susceptor [71]. The absence of binding agent causes the deposition of the susceptor particles due to the density difference, which results in non-uniform heating. The amount of susceptor present in the microwavable PCM, latent heat of the PCM and quantity of microwavable PCM determines the optimum microwaving time [71, 72].

MATERIAL SELECTION

During the selection of the PCM, the factors that have to be seriously noted are [73]:

1. High value of latent heat of fusion.
2. Appropriate transition temperature.
3. High specific heat capacity.
4. High thermal conductivity.
5. Chemical stability and non-corrosiveness.
6. Low vapor pressure at operational temperature.
7. Small volume change during solidification.
8. Little or no sub-cooling.
9. It should not be flammable.
10. Non-hazardous and no phase segregation.
11. No incongruent melting.
12. Availability and low cost.

The stability of the PCMs were found through thermal cycling tests by many researchers [24,39,75-77]. By introducing a nucleating agent in the PCM, the problem of sub-cooling can be solved. Incongruent melting can be avoided by using a PCM of suitable thickness [74]. Upon cycling, separation of phases with different compositions takes place due to the presence of several components in the phase change material. This is called as phase separation which reduces the heat storing capacity of the material. The presence of impurities reduces the thermal energy storage capacity of the PCM [78]. Usually for the hot food storage FSM65PCM (Form Stable 65 Microwavable PCM) is used. The transition temperature of this PCM compound lies between 65°C-68°C. It is an organic type PCM compound. Organic type PCMs were studied by many researchers and they identified some suitable materials for the energy storage [13,79-81]. Low thermal conductivity is the main disadvantage of organic type PCM [82]. The presence of graphite in the FSM65PCM increases its thermal conductivity and also acts as microwave susceptor to absorb the microwave energy. The FSM65PCM is shape-stabilized due to the blending of polymer [71,72]. It is not flammable. It undergoes little sub-cooling [83]. Energy storage composite with an organic PCM were studied by Feldman [84]. During repeated 1500 thermal cycles, there is no regular degradation in the melting point of the FSM65, which is a commercial grade PCM [24,39]. It consist of all the required characteristics of the PCM compound for the application of food storage.

Technical Specification:

Product : savE® Description : Organic material
Series : FSM65 Appearance : Black Solid

Property	Value*	Test Method	Test Conditions (if any)
Melting Temp (°C)	66-68	PLUSS® T-History	@ 75°C Liquid Bath
Freezing Temp (°C)	65.0	PLUSS® T-History	@ 55°C Liquid Bath
Latent Heat (kJ/kg)	150	PLUSS® T-History	@ 63 to 73°C
Solid Density (kg/m3)	845	PLUSS® Internal	@ 30°C
Solid Thermal Conductivity (W/mK)	0.25	KD2Pro	@ 30°C
Base Material	organic		
Congruent Melting	Yes		
Flammability	No		
Thermal Stability (Cycles)	~2000	PLUSS® Internal	
Maximum Operating Temperature (°C)	120		
Flash Point (°C)	200		

* Nominal Values. Actual values mentioned in Test Certificate

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Figure 6: Properties of FSM65PCM (PLUSS Technology) [83]

PREPARATION PROCESS OF REQUIRED PCM

In 2013, Samit Jain et al filed a patent on the topic "Treated fiber reinforced form stable phase change material" [27]. The preparation process of the Reinforced Form Stable 65 PCM is obtained by the following process. A 1liter stainless steel cylindrical flat bottomed container is placed on a hot plate. 140 g of stearic acid was added in the cylinder and maintained at 75°C -80°C. With continuous stirring 8 g of Styrene Ethylene Butadiene Styrene (SEBS) was added. The Globule structured Gel like mixture gets suspended over the liquid surface. The stirring is continued until the mixture becomes uniform. The globules of SEBS starts to homogenize and get mixed with stearic acid by increasing the temperature to 105°C -110°C. Constant stirring after 45 minutes in this temperature the mixture transforms into uniform sticky gel. Then 1.5 g chemically treated fiber PET (Polyethylene Terephthalate) fiber was added and mixed uniformly. Thus the Reinforced Form Stable 65 PCM is formed.

Samit Jain filed a patent on the topic "Composition of microwavable phase change material" [71]. Microwavable PCM can be prepared by the following process. In a stainless steel container 7.5 grams of expanded powder graphite was mixed with 150 grams of RFS65PCM, which is at 110°C using a stirrer. And then casting is done in required shape,

followed by cooling and solidification at room temperature. The addition of expanded graphite increases the thermal diffusivity [85, 86], and uniform heat transfer is obtained by the suspension of the graphite particles in the shape stabilized PCM composite. By experimenting, Samit found that the optimum microwaving time for 430 grams of save FSM65PCM was found to be 3min 30sec and this time varies with the amount of PCM composite (microwavable) involved. The above results can also be obtained in other ways, if the person is skilled and knowledgeable.

CONCLUSIONS

FSM65PCM composite has the best suitable characteristics for the application in food storage. PLUSS technology is the supplier of FSM65PCM [87]. Thermal properties of the material are mentioned in the technical data sheet provided by the manufacturer [83]. It can be manufactured in the form of sheets, pebbles or in any of the required form [2]. Researchers are trying to prepare PCM composite with different combinational characteristics, which is fine-tuned for a particular application. Contradictions exist in the thermo physical properties of the PCMs, like latent heat of fusion, thermal conductivity and density. This is due to the lack of international standards for testing the PCM [88]. The heat retention ability of the food storage containers can be improved with the implementation of the PCM, thus making way for the healthy life style of children.

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